Title:	Arctic Domain Awareness Center (ADAC) Marine Spill Modeling Working Group: Sea Ice Model Provenance
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Intended for:	Report
Issued:	2021-01-26

Arctic Domain Awareness Center (ADAC)
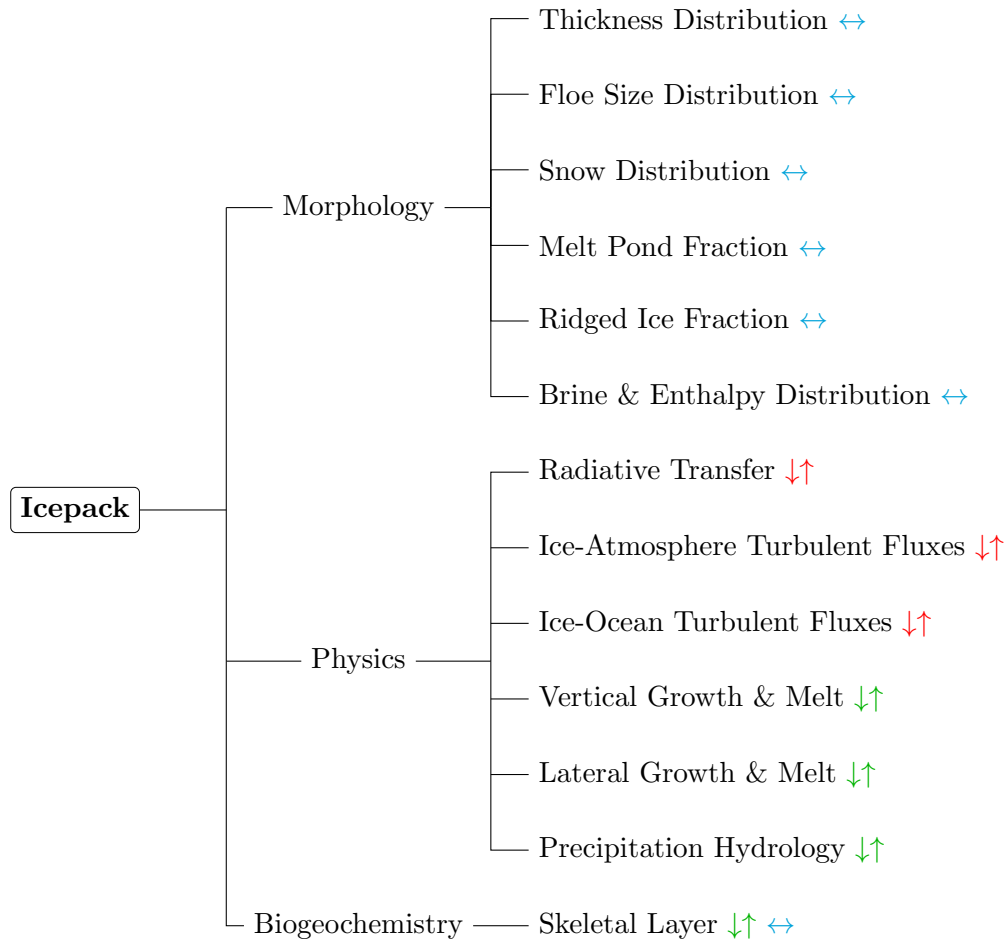Marine Spill Modeling Working Group

Sea Ice Model Provenance

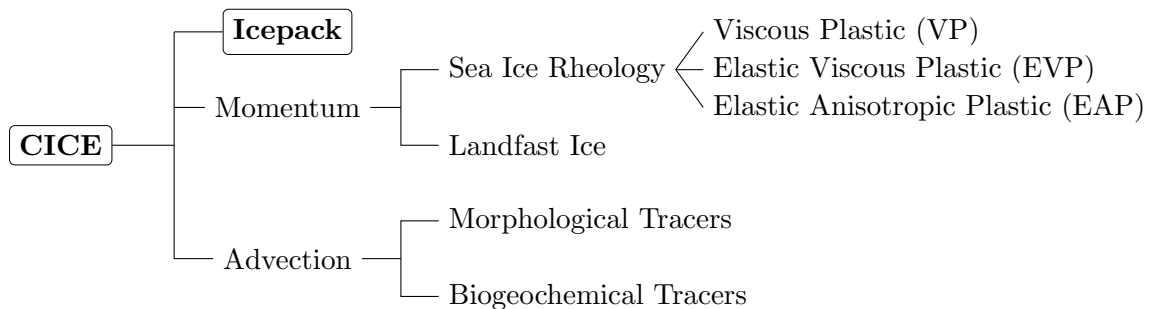Andrew Roberts[1], Elizabeth Hunke[1], Bonnie Brown[2], and Nicole Jeffery[1]

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January 25, 2021

Icepack

- Morphology
  - Thickness Distribution ↔
  - Floe Size Distribution ↔
  - Snow Distribution ↔
  - Melt Pond Fraction ↔
  - Ridged Ice Fraction ↔
  - Brine & Enthalpy Distribution ↔
- Physics
  - Radiative Transfer ↓↑
  - Ice-Atmosphere Turbulent Fluxes ↓↑
  - Ice-Ocean Turbulent Fluxes ↓↑
  - Vertical Growth & Melt ↓↑
  - Lateral Growth & Melt ↓↑
  - Precipitation Hydrology ↓↑
- Biogeochemistry
  - Skeletal Layer ↓↑ ↔

Icepack as an example of a state-of-the-art sea ice physics and biogeochemistry column package. Arrows indicate energy (↓↑) and mass (↓↑) flux exchange with the ocean and atmosphere, as well as horizontal advection (↔) using a dynamical core with Icepack, such as CICE. Addition of oil to Icepack would require a constituent hydrocarbon tracer, in turn affecting each of the morphology, physics and biogeochemistry of the model. Diagnostic tracers usedful for oil spill tracking, such as sea ice age, are available but not listed here.

CICE

- **Icepack**
- Momentum
  - Sea Ice Rheology
    - Viscous Plastic (VP)
    - Elastic Viscous Plastic (EVP)
    - Elastic Anisotropic Plastic (EAP)
  - Landfast Ice
- Advection
  - Morphological Tracers
  - Biogeochemical Tracers

CICE as an example of a dynamical core that uses a column package to represent sub-grid scale physics and biogeochemistry with Icepack as a submodule. As with other dynamical cores, CICE also includes infrastructure for running the model and providing output (not shown), and offers a choice of three methods for modeling internal ice stress: VP, EVP and EAP.

| Model[†]	Sea Ice Lead[‡]	Domain	DyCore[§]		Column[ξ]	Max. Timescale
a) Prominent sea ice component models applicable to coupled configurations						
CICE	LANL	global	native	ESQ	Icepack	centennial
MPAS-SI	LANL	global	MPAS	EU	Icepack	centennial
neXtSIM	NERSC	northern	native	LC	native	seasonal
DEMSI	LANL	northern	LAMMPS	LD	Icepack	centennial
TOPAZ	NERSC	northern	native	LD	native	synoptic
b) Coupled forecast systems expected to be applicable to Arctic oil spill tracking						
ESPC	NRL	global	CICE	ESQ	Icepack	synoptic
CCMEP	ECCC	global	CICE	ESQ	Icepack	synoptic
HYCOM-CICE	DMI	northern	CICE	ESQ	Icepack	synoptic
TOPAZ4	NERSC	northern	native	ESQ	native	synoptic
RTOFS	NWS	global	CICE	ESQ	Icepack	synoptic
c) Examples of U.S. earth system models adaptable for studying Arctic oil spill impacts						
E3SM	LANL	global	MPAS-SI	EU	Icepack	centennial
CESM	NCAR	global	CICE	ESQ	Icepack	centennial
RASM	NPS	northern	CICE	ESQ	Icepack	decadal

Sea Ice Model Provenance: U.S., Canadian, Danish and Norwegian Models surveyed by the meter-scale working group for potential oil spill response and planning from 2021 onwards. Models have been divided into stand-alone (a) sea ice models, (b) coupled atmosphere-sea ice-ocean-land hydrology synoptic analysis and forecast models, and (c) fully coupled earth system models used for decadal to multi-centennial climate studies. In 2020, not all models listed as using CICE use the latest version that includes the meter- to sub-grid scale physics and biogeochemistry of Icepack, but a switch to Icepack is anticipated starting in 2021. Acronyms are as follows:

† Codes - CICE Consortium sea ice model; MPAS-SI - Model for Prediction Across Scales, Sea Ice component; neXtSIM: neXt generation Sea Ice Model; DEMSI: Discrete Element Model of Sea Ice; TOPAZ: Ocean analysis and forecast system of the Nansen Environmental and Remote Sensing Center; ESPC: Earth System Prediction Capability of the U.S. Navy; CCMEP: Canadian Centre for Meteorological and Environmental Prediction forecast model; HYCOM-CICE: Configuration of the Hydbrid-Coordinate Ocean Model coupled to CICE; TOPAZ4: Fourth operational version of TOPAZ; RTOFS: Global Real-Time Ocean Forecast System; E3SM: Department of Energy Exascale Earth System Model; CESM: Community Earth System Model; RASM: Regional Arctic System Model.

‡ Institutions leading sea ice development within the stated codes - LANL: Los Alamos National Laboratory; NERSC: Nansen Environmental and Remote Sensing Center. NRL: Naval Research Laboratory; ECCC: Environment and Climate Change Canada; DMI: Danish Meteorological Institute; NWS: U.S. National Weather Service; NCAR: National Center for Atmospheric Research; NPS: U.S. Naval Postgraduate School;

§ Dynamical Cores - MPAS: Model for the Prediction Across Scales; CICE: Native consortium Dynamical Core; LAMMPS: Large-scale Atomic/Molecular Massively Parallel Simulator; T*native* refers to a dynamical core that does not access external software. Key: E - Eulerian DyCore on either a structured quadrilateral (SQ) or unstructured (U) mesh; L - Lagrangian DyCore, either using continuum mechanics (C) or the discrete element method (D).

ξ Sub-grid scale column physics and biogeochemistry - Icepack: CICE Consortium saline ice package; *native* refers to a sub-grid scale representation that does not access external software.

| Lagrangian Continuum | Lagrangian Discrete | Eulerian Unstructured | Eulerian Structured |
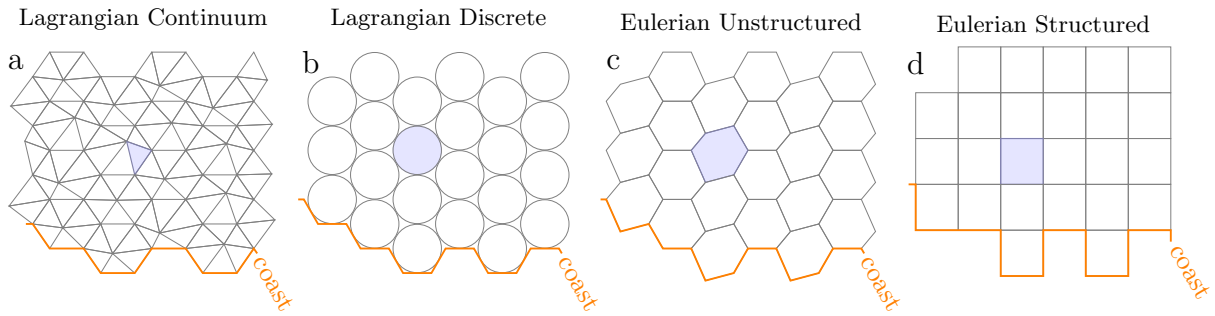
Meshes for dynamical cores within which sub-grid and meter scale sea ice physics and biogeochemistry are represented statistically (blue shading) to simulate oil spills . Examples from the table include (a) neXtSIM, (b) DEMSI, (c) MPAS-SI, and (d) CICE. The location of the vertices in (a) and discrete elements in (b) move with the pack, whereas the mesh is fixed in space for (c) and (d). The mesh illustrated in (d) is both structured and quadrilateral.